Received Date: 16/02/2020 Acceptance Date: 27/02/2020 Publication Date: 29/02/2020

Pressure in a porous medium as an indicator of the observed liquid level in a cane diffuser bed

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Abstract: *The liquid level in a diffuser is currently controlled by the inspection of a group of sight glasses. The technique is limited by manual data acquisition and short sampling time interval, therefore, new methodologies, such as use of manometers as an indicator of the liquid holdup have been developed. Nevertheless, no satisfactory results have been achieved on a laboratory scale, and those from experimental tests performed on a full scale have not been validated by subsequent research.*

This study analyses the viability of using manometers to assess the observed liquid level in a cane diffuser bed towards optimising percolation rates and improving the extraction process. Liquid levels were measured by manometers at the Maidstone factory and the experimental data were validated by a mathematical model based on Darcy's equations. The analysis of variations in the cane bed permeability revealed a linear permeability function fitted the experimental data with the theoretical data. Reproducibility tests were performed to confirm the results.

An experimental method is provided for the analysis of variation of the physical properties of a porous media (sugarcane), such as permeability and pressure, and can be applied to other system (e.g., geothermal engineering, underground water,). A novel technique determined the liquid holdup within a cane bed. A comparative analysis of the two techniques was performed for measuring the liquid level.

Key Words: *Diffuser, liquid level, flooding, full-scale tests, pressure, permeability, and cane compaction.*

1. INTRODUCTION:

The sucrose contained in the cane juice is separated from the remainder of the cane by mills tandem or diffusers [1]. The latter show higher efficiency and lower consumption of electricity, maintenance, and capital costs in comparison with the former [2]. For example, the replacement of traditional milling systems by diffusers increases sugar production from 3 to 6 % [3].

Diffusers use two sucrose extraction processes from prepared cane, namely washing- sucrose is mechanically removed from the surface of the fibre by water, and diffusion-sucrose is transferred from the fibre cells (higher sucrose concentration) to the surrounding extract (lower sucrose concentration) [4].

A diffuser is composed of stages, whose number depends on its crushing capacity. The crushing capacity of ‘Maidstone diffuser’ is 300 Tons of cane per hour (THC), therefore, it involves 12 stages that are 9 m wide and 4.1 m long each. Stages are characterized by a tray that collects the liquid at the screen of the diffuser; a screen, located at the bottom of the diffuser, is a perforated plate that filters the juice from the cane bagasse. The stages also have a spray that distributes the juice at the top of the sugarcane bed; a spray deflector device adjusts the flap to a bypass or recycle position. In the latter, the liquid flows through the same stage, whereas in the former, it returns to the previous stage. The operator controls and adjusts the spray deflector position according to a visual inspection of the observed liquid level from the sight glasses. However, such an adjustment should be automated, since a manual one requires 12 operators while the diffuser is under operation.

The observed liquid level measures are not accurate, because the viewable area of the sight glass enables the observation of the liquid level only near the sidewalls of the diffuser. Moreover, measurements cannot be taken in all stages, since the sight glasses are not installed in all of them, or sometimes, a sight glass is damaged, which compromises its visibility. Fast fluctuations of the observed liquid level across the cane diffuser bed are a critical problem, because the operators record the data manually. Therefore, the observed liquid level should be assessed online for the estimation of the optimal percolation rate, maximization of sucrose extraction, and avoidance of flooding in the cane bed.

Manometers and conductivity meters have measured the observed liquid level in the cane bed, however they are still in a research phase. Floating devices are not suitable, since the diffuser must be flooded.

Pressure variations in a cane diffuser were first measured by a pressure transductor installed on its wall at Amatikulu mill, in South Africa. Pressure transmitters with a flush mounting diaphragm were then installed on the wall of the diffuser at Felixton mill. Electronic pressure transmitters were installed vertically, 0.45 m, 0.85 m, 1.050 m and 1.45 m above the screen, and the pressure profile of the cane bed was calculated by Carman-Kozeny Equation [5].

The use of pressure transductors as an indicator of the observed liquid level was assessed for two seasons in six out of the 16 stages at Amatikulu mill for adjustments and control of the spray deflector position. The extraction was improved in the last season due to the high preparation index of the sugarcane, since an increase in the open cells enabled mass transfer. However, if the liquid had not been controlled, the normal consequence of the increased cane preparations would be flooding in the cane bed.

According to Rein and Ingham [5], the cost of the automation of diffuser sprays is justified by the reduction in the imbibition liquid and the coal used to heat it. Therefore, the installation of the pressure transductors would be paid within a quarter of the season. Although the results yielded a patent, the method was not accepted, since the results were noisy and questionable.

The experimental tests performed by Loubser and Jensen [6] mapped the pressure distribution and flow through a cane bed on a laboratory scale. The friction pressure loss matched the gravitational pressure at a steady state. A slight variation in the static pressure was associated with the distribution of permeability; therefore, the pressure cannot be used as an indicator of the liquid holdup under such conditions. The authors used a rectangular model of glass diffuser, which had a 1.5 m long and 1 m high front.

The results from the test performed on both full and laboratory scales differed, because the latter used the same variety of cane and the effects of the adjacent stages were disregarded; as a consequence, the permeability effects were not perceptible and the cane compaction in the laboratory might not be the same of the diffuser.

Experimental tests were conducted on a plant scale, pressure variations were computed by Darcy's law, and pressure profiles were created according to different permeability functions [7]. A linear function of permeability validated the theoretical model, and the comparison between theoretical and experimental data determined the observed liquid level should be assessed through pressure variations.

2. EXPERIMENTAL PROCEDURE FOR THE MEASUREMENT OF LIQUID LEVELS BY MANOMETERS

Experimental trials were conducted on the Maidstone diffuser by four manometric tubes, sockets (127 mm), nipples and isolation valves installed on one of its walls. The sockets were fitted with transparent plastic tubing and provided measurements relative to atmospheric pressure, as shown in Figure 1. They could be removed for cleaning, thus preventing the bagasse from blocking the liquid flow in the tube.
The plastic tubes were fixed on a wooden panel, so that the liquid level measured by manometers at different heights on the diffuser's wall could be visualized. Therefore, depending on the liquid level, some manometers could not show the variation in the liquid level.

Figure 1. Installation of manometric tubes on the wall of the diffuser, near the sight glass, where measurements of the observed liquid level were recorded.

Figure 2A shows the manometric tubes. The grey rectangle represents the sight glass (Figure 2A), Z_L is the observed liquid level, W is the cane bed height, and M_1 is the liquid level observed in the first manometric tube, according to its location.

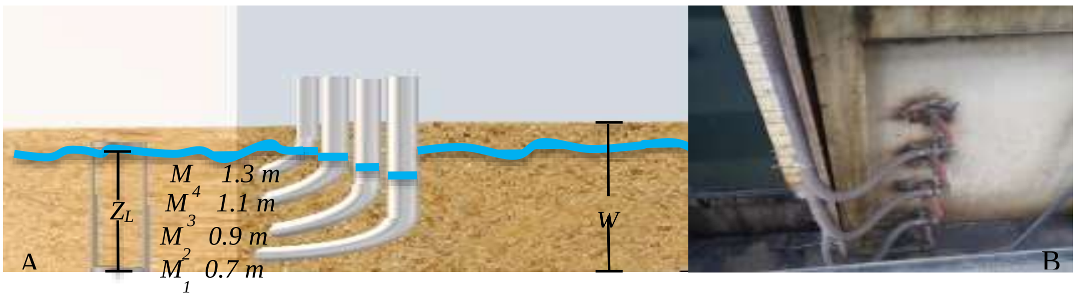

Figure 2. A. Manometric tubes installed on the wall of the diffuser at the fourth stage. **B**. Manometric tubes installed on the wall of the diffuser after one year with no maintenance

M_1 represents the position of the manometric tube located 0.72 m from the screen of the diffuser. The resolution of the manometric tubes is unknown, since the liquid level never decreased to a level lower than 0.9 m. However, the maximum liquid level measured on the manometers corresponds to the height at which they were installed.

The manometric tube (P_1) was not working, consequently, data were not considered in the analysis of the results. The system must be frequently cleaned for avoiding bagasse blockages of the plastic tube (see Figure 2B).

In the present study, some experiments conducted determined the relationship between pressure and observed liquid level under normal operating conditions and when the recirculation pump was turned off. This pump pumps the liquid from the fifth stage to the fourth one, where the measurements of the liquid level on the manometer and the observed liquid level were concomitantly recorded.

Data validation: The liquid holdup is the liquid retained in the cane bed, and the observed liquid level is the one observed from the sight glass. The latter has been used as an indicator of the local liquid holdup, since such a level is affected by diffuser and pump operations (it decreases when the pump is turned off). The observed liquid level was not used as an indicator of the liquid holdup on a big scale, since this level in the sight glass represents only a small area of the entire stage. However, it is useful in this research, because the manometric tubes were installed 50 cm from the sight glass and assessed only the local liquid level in a small region of the diffuser. The data were recorded at least three times under different conditions for assuring the repeatability of the results.
Cases 1 – 4: Cases 1 and 2 correspond to pressure variations when the liquid inside the cane bed is drained by the deactivation of the fourth pump, whereas cases 3 and 4 correspond to pressure variations under normal operating conditions.

Mean Square Error: Different permeability functions were tested for determining the distribution of pressure along the cane bed in the fourth stage, and the experimental data were compared with the theoretical data for the establishment of the mathematical model error.

Characteristics of the cane juice: The brix of the juice depends on the characteristics of both cane and mixed juice. It varied from 9.5 % to 12 % in the cane diffuser bed, whereas the juice purity ranged from 83.9 % to 86.5 %. The density of the mixed juice was calculated by the web site of Jayes, 2018, with the use of purity and brix values. The density varied from 1036.8 to 1049.6 kg/m^3.

Correlation coefficients: The correlation coefficient of two random variables is a measure of their linear dependence. If each variable has *N* scalar observations, the Pearson correlation coefficient is defined by Equation :

$$\rho(A.B) = \frac{1}{N-1}\sum_{i=1}^{N}\left(\frac{\overline{A_i-\mu_A}}{\sigma_A}\right)\left(\frac{B_i-\mu_A}{\sigma_B}\right) \quad (1)$$

Where μ_A and σ_A are the mean and standard deviations of *A*, respectively, and μ_B and σ_B are the mean and standard deviations of *B*. Alternatively, the correlation coefficient can be defined in terms of covariance of *A* and *B* in Equation 2:

$$\rho(A.B) = \frac{cov(A.B)}{\sigma_A \sigma_B} \quad (2)$$

The correlation coefficient matrix of two random variables is the matrix of correlation coefficients for each pairwise variable combination as shown in Equation 3.

$$R = \begin{pmatrix} \rho(A.A) & \rho(A.B) \\ \rho(B.A) & \rho(B.B) \end{pmatrix} \quad (3)$$

A and *B* are always directly correlated to themselves. The diagonal entries are only 1 as shown Equation 4.

$$R = \begin{pmatrix} 1 & \rho(A.B) \\ \rho(B.A) & 1 \end{pmatrix} \quad (4)$$

3. MATHEMATICAL MODEL FOR PRESSURE CALCULATION

Darcy's equation [10], [11] described the flow of the liquid through the cane bed (porous medium). The juice was assumed sprayed at a rate high enough to ensure the cane bed was saturated, i.e., the percolation rate was sufficient in the surface and resulted in a unidirectional vertical flow. Equation 5 gives the fluid velocity (m/s) in terms of negative gradient of the pressure (Pa) as a function of the observed liquid level (z).

$$u = -k(z)\nabla\emptyset \quad (5)$$

where k is the permeability of the material (m/s) and $\nabla\emptyset$ is a measure of the variation of the fluid potential, defined as the height to which water can rise in the manometric tube. The negative signal in Darcy's equation indicates the hydraulic level always decreases in the direction of the flow. The potential theory predicts flow in a porous medium. The potential is given by Equation 6 [12].

$$\emptyset = p - pgz + \rho\frac{v^2}{2} \quad (6)$$

where p is pressure (Pa) given by the fluid height above a point, z is the height at some reference level, ρ is the density of the liquid (kg/m^3), and g is the gravitational acceleration (m/s^2) with a negative direction according to the coordinate system shown in Figure 3. The second term of Equation 6 represents the gravitational potential, and the third term represents the kinetic energy.

The viscous effects are predominant over turbulent effects because the average percolation rate is 1.5 m^3/m^2/min; therefore, the velocity term was neglected in Equation 6. Measurements of percolation rates in full-scale diffusers covered a 0.1 to 0.2 m^3/m^2/min range [4], and percolation rates in laboratory columns generally range between 0.3 and 1.0 m^3/m^2/min and largely dependent on the fibre packing density [13].

The substitution of Equation 6 (the potential) in Equation 5 and the separation and discretization of the variables result in Equation 7.

$$\frac{\partial p}{\partial z} = \frac{u}{k(z)} - \rho g\frac{\partial z}{\partial z} \quad (7)$$

The first term of the right side represents the effect of viscous forces on the pressure variation caused by the friction between the fluid and the porous medium. The second term represents the hydrostatic pressure. The integration of Equation 7 gives

$$p = u\int_0^z \frac{\partial z}{k(z)} - \rho g\int_0^z \partial z + c \quad (8)$$

Due to the conservation of momentum and the conservation of mass, the fluid is incompressible, therefore, the velocity of the flow is considered constant, and is not integrated into Equation 8.

The initial conditions ($p=0$ in $z=0$) and ($p = p_\varphi$ in $z = h$) were used in Equation 8 to determine the integration constant (c) is equal to zero and compute p_φ, respectively.

$$p_\varphi = u\int_0^h \frac{dz}{k(z)} - \int_0^h \rho g dz \quad (9)$$

Separating variables and integrating Equation 9 provide

$$u = \frac{\rho g h + p_\varphi}{\int_0^h \frac{dz}{k(z)}} \quad (10)$$

Substituting Equation 10 into Equation 8, one has

$$p(z) = \frac{h + (P_\varphi)}{\int_0^h \frac{dz}{k(z)}}\int_0^z \frac{dz}{k(z)} - \rho g z \quad (11)$$

The second term of the right side of Equation 11 represents the hydrostatic component, and the first term represents the permeability effect. The integral in the denominator denotes the average permeability, whereas the integral in the numerator represents the local permeability associated with the terminal velocity.

The spatial coordinate system is right-hand-oriented with y-axis pointing upward; therefore, the permeability increases with the y-axis (a vertical flow was considered in Figure 3).

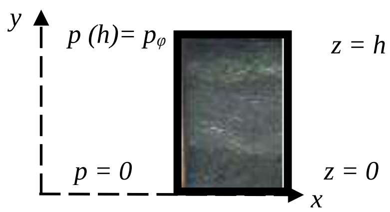

Figure 3. Initial conditions used in Equation 11

$P=0$ is the atmospheric pressure, and p_φ is an unknown constant pressure (p_φ), obtained from the experimental data.

3. PERMEABILITY VARIATION THROUGH THE CANE BED

The assessment of the variation in the cane bed permeability is a complex and challenging task that plays a key role in the description of the percolation rate through the cane bed. It is performed with the use of experimental porosity-permeability relationships. However, such relationships are not useful, since permeability varies through the diffuser due to the cane characteristics, preparation index, sugarcane porosity, and sugarcane compaction.

Lifting screws unpack the sugarcane and regulate the permeability profile. Immediately after lifting screws, the cane bed may show regions of low permeability above regions of high permeability. However, a low permeability at the bottom is the natural tendency. Voids can appear, depending on the permeability variation through the cane bed, and it is not a locally determined phenomenon.

The pressure profile in the cane bed was determined by linear and exponential permeability functions in Equation 11. Quadratic permeability functions were not considered, since the permeability in the lower and upper parts of the cane bed is the same, and experimental data indicate it should be different.

4. ANALYSIS OF DIFFERENT PERMEABILITY FUNCTIONS FOR THE DETERMINATION OF THE PRESSURE PROFILE

The theoretical permeability (Figure 4A) was computed considering *z* varied from 0 m to 1.7 m in a 0.1 m variation interval, while the permeability constants (η_1 and η_2) were adjusted for the obtaining of a 0.005 m/s average permeability (K_m), as shown in Table 1. Loubser and Jensen (2015) determined this value experimentally.

Table 1. Description of the permeability function parameters

Permeability Equation	η_1	η_2	K_m (m/s)
$k(z) = \eta_1 z + \eta_2$	8	330	0.005
$k(z) = exp(\eta_1 z) + \eta_2$	1	-0.4778z	0.0051

Two linear functions were analysed, since they provided different results (see Figures 4-5 and Table 1).

The permeability is higher on the cane bed surface and lower at the bottom of the diffuser (Figure 4A), due to the compaction of the cane. However, the pressure decreases after 0.8 meters, and no physical reason has been attributed to such a behaviour.

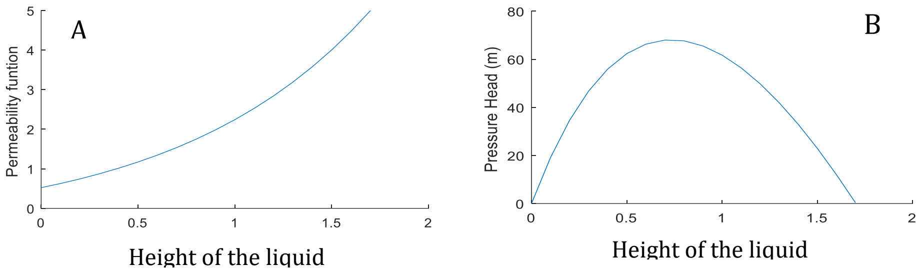

Figure 4. A. Exponential permeability function; **B**. Pressure distribution through the cane bed calculated by the exponential function of permeability

The permeability profile (Figure 4A) distorts the natural pressure variation (P), as shown in Figure 5. Moreover, the pressure profile should have no negative slope, as confirmed by Rein and Ingham (1992) and the experimental data.

Figure 5 displays the theoretical pressure calculated by the exponential function of permeability, where *P* is the pressure calculated with the use of measurements of the observed liquid level (Z_L) in Equation 11, and P_2, P_3, and P_4 are the pressures calculated with the liquid level measured by the manometers (Z_2, Z_3, Z_4) in Equation 11.

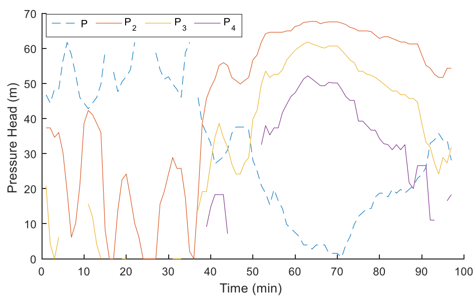

Figure 5. Theoretical pressure calculated by the exponential function of permeability (Figure 4) in Equation 11.

Pressure variation (Figure 5) is high enough to be originated by a liquid column smaller than 1.7 meters; therefore, the exponential permeability function did not provide satisfactory results. A linear function of permeability was used in Equation 11 (Figures 6-7), and the calibration constant (η_1) in the simulations performed on Matlab program affected the pressure curvature.

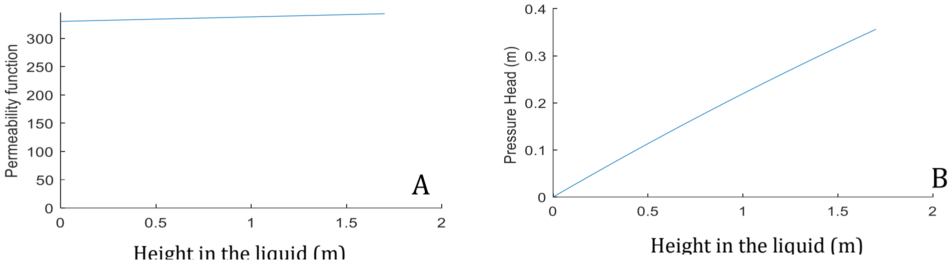

Figure 6. A. Linear permeability function; **B**. Pressure distribution through the cane bed calculated by the linear function of permeability with constants $\eta_1 = 8$ and $\eta_2 = 344$

The linear function of permeability (Figure 6A) enables pressure *P* to match pressures P_2, P_3, and P_4, as shown in Figure 7. The experimental data helped to find the correct permeability function, and, according to the previous results, the pressure should vary linearly for keeping the same fluctuation of the pressure curves.

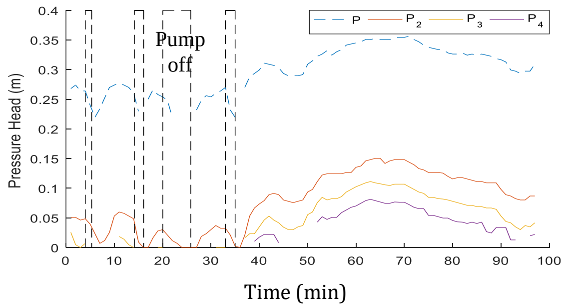

Figure 7. Theoretical pressure calculated by the linear function of permeability (Figure 9) in Equation 11

The dotted lines in Figure 7 indicate when the fourth pump was turned off. This pump sprays liquid on the top of the cane bed.

The observed liquid level creates a higher pressure (P) (Figure 7), because it was generated by the higher column of the liquid. The manometric tubes installed near the surface of the cane bed show a lower pressure (*P_4*) than the others, since they measured a smaller column of liquid, due to their location. The difference between the readings of each manometer may be caused by the cane compaction and friction and hydrostatic effects.

6. CASES 1 AND 2

Cases 1 (Figure 7) and 2 (Figure 8) correspond to the pressure variation when the liquid inside the cane bed is drained by the deactivation of the fourth pump.

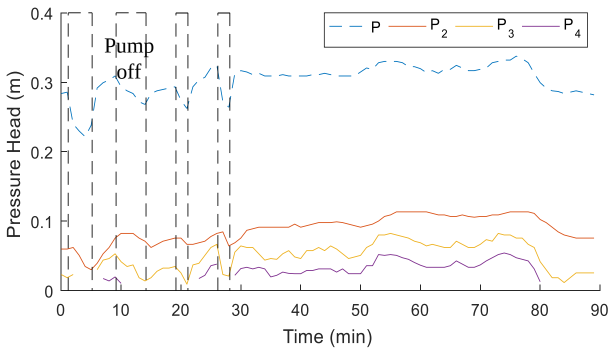

Figure 8. Pressure variations caused by the operation of the fourth pump (case 2)

The pressure decreases when the pump is turned off. This effect is more pronounced in case 1 than in case 2, as shown in Figure 8.

7. CASES 3 AND 4

Cases 3 and 4 correspond to the pressure variation under normal operating conditions. The liquid level data on the manometers were recorded under normal operating conditions on different days for 60 minutes for case 3, and 75 minutes for case 4, as shown in Figure 9.

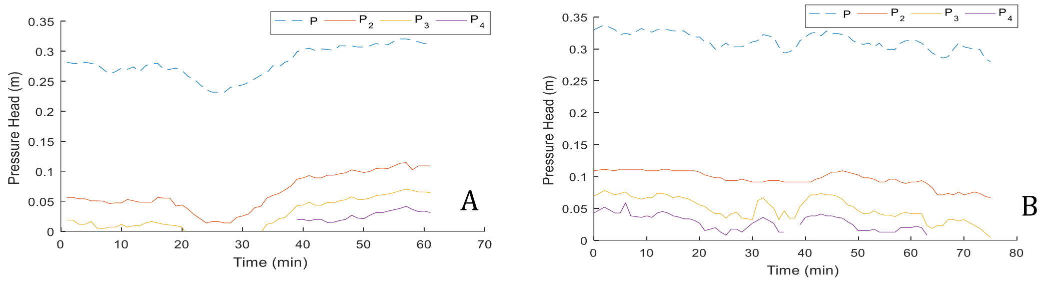

Figure 9. A. Pressure variation under diffuser's normal operating conditions (case 3); **B.** Pressure variation under diffuser's normal operating conditions (case 4)

All pressure curves in the previous graphs (Figures 7-8) show similar fluctuations; however, they are dislocated to a certain value, called calibration parameter, which adjusts pressures P_2, P_3 and P_4 to pressure P. This parameter must be determined to control the liquid level through the diffuser and for the automation of the spray deflector position that distributes the liquid onto the bed surface, according to the settings selected. The calibration parameters were calculated by the comparison of pressure P with the pressure of the three manometric tubes until the maximum Mean Square Error (MSE) between them had been found (see Table 2).

Table 2. Calibration parameters for the pressure curves

Figure	Calibration parameters for P_2, P_3, P_4 (m)								
	P_2	MSE_2	$Data_2$	P_3	MSE_3	$Data_3$	P_4	MSE_4	$Data_4$
Figure 7	0.217	0.94	97	0.255	0.96	75	0.28	0.975	50
Figure 8	0.215	0.5	90	0.256	0.87	87	0.28	0.92	62
Figure 9 A	0.217	0.6	72	0.262	0.81	72	0.29	0.83	58
Figure 9 B	0.216	0.94	61	0.26	0.94	54	0.28	0.96	23

Data represent the number of samples recorded per trial. The second manometric tube (M_2) recorded the largest number of measures due to its location, however, it shows the lowest MSE, while the fourth manometric tube (M_4) recorded the smallest number of data, and shows the highest MSE (Table 2).

The permeability is higher in the surface and lower in the bottom; consequently, the pressures near the bottom can significantly change in relation to the pressures on the surface. The third and second manometric tubes recorded the same number of samples (Figure 9 A). However, the third shows a significantly higher MSE because the permeability changes through the cane bed. The same is shown in Figure 8 in Table 2; the only difference is the third tube recorded three fewer data than the second.

The analysis of the results revealed the calibration parameters for pressures P_2, P_3 and P_4 tend to converge in almost all cases.

Finally, the variation coefficients of the calibration parameter of P_2, P_3, and P_4 were 0.4 %, 1.28 %, and 1.77 % respectively. Variation coefficient (VC) is a measure of relative variability, computed as the ratio of standard deviation divided by the mean value, and expressed as a percentage.

8. Effect of the cane bed height on the pressure distribution through the cane bed

The cane bed height varies constantly through time and does not affect pressure variations, as shown in Figure 10. Therefore, a constant cane bed height could be used in the mathematical model.

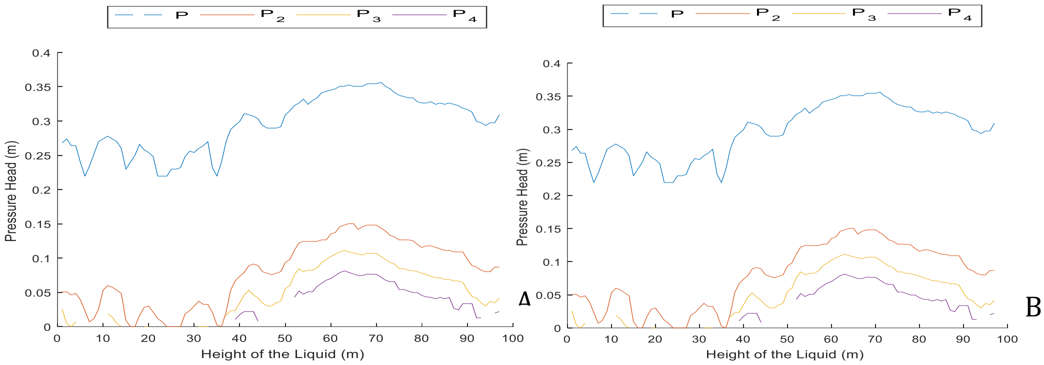

Figure 10. **A**. Pressure variation when *h* is a variable; **B**. Pressure variation when *h* is a constant (1.7 m)

8. COMPARATIVE ANALYSIS AMONG DIFFERENT TECHNIQUES THAT MONITOR THE OBSERVED LIQUID LEVEL IN A CANE DIFFUSER BED

This comparative analysis assessed pressure and conductance as an indirect measurement of the liquid holdup. The advantages and disadvantages of each method are shown in Table 3.

Table 3. Comparison between conductance and manometric liquid levels as an indirect measure of the observed liquid level

Parameter	Conductance	Pressure
Sample rate	Conductance measurements in a cane diffuser are simple, fast, suitable for routine testing and long-term monitored, since they can be configured at different sample rates	The conductance sampling rate is lower than the pressure sampling rate because the data in the manometers were recorded manually.
Boundaries of the measurements	The distribution of the current through the cane bed is unknown. The conductivity meter can detect fluctuations between electrodes separated by three meters, but not conductance variations when the electrodes are nine meters apart. Three electrodes, located 3 meters from each other, can provide a measure of conductance through the whole diffuser's stage, since the stage is 9 m wide.	The manometers must be installed at least in three points in every stage, since the liquid holdup is variable. However, such measurements could not determine pressure variations throughout the stage, because manometers cannot be installed in the middle of the stage and the boundaries of pressure measurements are unknown
Flooding detection	The conductivity meter can detect flooding in the cane bed with no other measurement, because the conductance of the three channels remains in specific values with no fluctuations when it is flooded. A conductance value may coincide with two observed liquid levels; therefore, the conductance of the cane bed should be associated with its height.	The manometric tubes can detect the liquid level, and a mathematical relationship between the liquid level on the manometer and the observed liquid level was established. However, they cannot detect flooding in the cane bed without a measure of the cane bed height.
Correlation Coefficients (Appendix A)	No mathematical relationship was established between conductance and observed liquid level, however, the correlation coefficient between them varied from 0.7 to 0.8 in all experimental tests conducted.	The relationship between liquid level and pressure is established by Eq. 7, and the correlation coefficients between the observed liquid level and the liquid level measured on the manometer varied from 0.876 to 1

9. CONCLUSIONS :

The analysis of the results revealed different permeability functions altered the pressure profiles. The experimental data match the theoretical data when a permeability linear function is calibrated.

The mathematical relationship between pressure and observed liquid level has been found. The calibration parameters (Table 2) fitted the pressure on the manometers with the pressure caused by the observed liquid level, and the calibration parameters variation was lower than 2%.
The effect of the cane bed height on the variation in the liquid level on the manometer is negligible, therefore, a constant value of the cane bed height can be used in the mathematical model.
The correlation coefficients show a strong relationship between observed liquid level and pressure, confirmed by reproducibility tests.

REFERENCES:

1. Palacios-Bereche, R., Ensinas, A., Modesto, M., and Nebra, S. (2014): Extraction process in the ethanol production from sugarcane – a comparison of milling and diffusion, *Chemical Engineering Transactions, 39* (1), 1519-1524
2. Faber, A.N. (2013), Características de los difusores y su aplicación en la extracción del jugo de caña, Proc. 3th, Congreso AETA, Guayaquil, 1-10
3. Van Hengel, A. (1990): Diffusion as steam saver, *Sugar Industry-Zuckerindustrie, 115*, (7), 551–554
4. Rein, P. (2007). *Cane sugar engineering*. Berlin: Bartens
5. Rein P. W. and Ingham P. T. S. (1992), Diffuser performance optimisation through the control of liquid flow patterns. Proc. Int Soc Sug Can Technol (ISSCT), Bangkok, Thailand, 211 – 222
6. Loubser, R. and Jensen, P. (2015), Modelling juice flow in a shredded cane bed, Proc.88th South Africa Sugar Technology Association, Durban, South Africa, 779 – 796
7. Breward, C., Hocking, G., Ockendon, H., Please, C., and Schwendeman, D. (2012), Modelling the extraction of sugar from sugar cane in a diffuser, Proc. MISG, Johannesburg, South Africa, 31–57
8. Segura-Angel, D., Love, D., Jensen, P., and Seleghim, P. (2019): Monitoring juice hold-up in a cane diffuser bed using electrical conductivity - Evaluation on a plant scale. *Sugar Industry-Zuckerindustrie 144,* (5), 3308-3315
9. Jayes, Wayne E. G. (2018). The Sugar Engineers. Available: <http://www.sugartech.co.za/density/index.php>. Access in: 11 Dec. 2018.
10. Bear, J. (1972). *Dynamics of Fluids in Porous Media*. New York: McGraw-Hill
11. Harr, M. E (1990). *Groundwater and Seepage*. New York: Dover
12. Kay, J. M. and Nedderman, R. M. (1985). *Fluid Mechanics and Transfer Processes*. England: Cambridge University Press
13. Lionnet G. R. E. (2005), The effect of selected factors on percolation in pilot diffusion columns. Proc.79th South Africa Sugar Technology Association, 249-257